UNIVERSITY OF ALBERTA

EVALUATION OF ECCENTRIC AND CONCENTRIC HAMSTRING AND QUADRICEPS STRENGTH RATIOS

BY

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DEDICATION

I would like to dedicate this work to a few key people who have helped me during my time in Alberta.

To my parents and my brother who within themselves are my source of strength and inspiration. Thank you for your continuing love and support in whatever I do. I thank you for reminding me that I can accomplish anything I want and most importantly teaching me the value of hard work, perseverance, and for always being there no matter where I may be.

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Chapter One

Introduction

In 1967 Hislop and Perrine[1] and Thistle, Hislop, Moffroid, and Lohman[2] introduced into the scientific literature the concept of isokinetic exercise. Isokinetic devices allow individuals to exert as much force as possible and angular movement at velocities between 0 to 500^0/sec. The isokinetic dynamometer produces an equalling counterforce to ensure a constant movement rate if the limb's angular rate of movement equals or exceed the preset velocity limit.[3-6]

Isokinetic resistance has several advantages over other exercise modalities. One advantage is a muscle group may be exercised to its maximum potential throughout a joint's entire range of motion.[6] For example, somewhere close to midrange of joint motion (where the muscle is at its optimum length tension relationship for the binding of actin and myosin and has its greatest mechanical advantage), the isokinetic dynamometer will maintain its preset velocity, and thus more force will be produced. Conversely, at the extremes of joint motion (where a muscle is at a physiological and mechanical disadvantage), the dynamometer will still maintain its preset velocity, but less force will be produced. Because there is no fixed resistance to move through the weakest point in a given arc of motion, isokinetic exercise facilitates a maximum voluntary force to be produced throughout the entire range of motion.[3, 6-35]

The ability of a muscle to generate tension throughout all or part of a joint's range of motion is known as a dynamic contraction.[4, 5, 7, 11-15, 17, 25, 36-38] Dynamic tension can be produced by either muscle shortening or lengthening. If the muscle is contracting while it is lengthening at the same time, the contraction is eccentric (lengthening) in nature.[4, 5, 7, 11-15, 17, 25, 37] If the muscle is contracting and shortening at the same time, the contraction is concentric (shortening) in nature.[5, 7, 11-13, 15, 17, 25] The recent development of newer active dynamometry instruments has permitted the quantification of a muscle's ability to produce concentric and eccentric tension. [3, 13-15, 17, 18, 20-22, 25, 29, 31-33, 39-47] Presently, the ratios of the different types of muscle contraction performed during isolation angle joint movement patterns and their role in rehabilitation has not been addressed.

Isokinetic exercises may be used to quantify a muscle group's ability to generate torque or force, and they are also useful as an exercise modality in the restoration of a muscle group's preinjury level of strength.[6, 8-10, 13, 15, 17, 20-22, 25, 29, 31, 32, 43, 46-48] This type of exercise may be submaximal and easily set through pain free ranges within the total available range of joint motion, and exercise velocities may be selected that have the least potential for joint trauma.[13, 18, 35, 40, 49-55]

Peak or average torque values are the isokinetic parameters most generally used to analyse human performance.[13, 39, 54-56] However, the interfacing of microprocessors with isokinetic dynamometers facilitates appraisal of torque at any point in the range of motion; this is called angle specific torque.[3, [13, 15, 17, 40, 48, 53-55, 57] Although the reliability of this practice has been questioned[58], it theoretically enables identification of torque at a predetermined point in the range of motion of a certain muscle group's contribution to the torque performance.[3, 13, 15, 17, 40, 48, 53-55, 57] The assessment of the muscular functions of strength and power are of particular importance in exercise science. Such tests are used to provide information regarding the relevance of strength and power to various physical pursuits, to identify talent, to develop athlete specific profiles and to monitor training progress or the progress of injury rehabilitation.[3, 15, 35, 48, 57, 59-61]

The ratio of maximal isokinetic concentric hamstring muscle strength relative to maximal isokinetic quadriceps muscle strength (H:Q ratio) is a parameter commonly used to describe the muscle strength properties about the knee joint.[9, 15, 28, 35, 36, 46, 55, 59] Conventionally, the H:Q ratio has been calculated as maximal knee extension strength obtained by a given knee angular velocity and contraction mode (isometric,[9, 53, 54, 59, 62-70] concentric,[9, 15, 26, 45, 53, 54, 64, 66-78] and eccentric)[15, 22, 26, 44, 45, 53, 71, 73, 74, 76-78]. The conventional concentric H:Q strength ratio is calculated by dividing maximal concentric knee flexor (hamstring) moment by the maximal concentric knee extensor (quadriceps) moment obtained at a given angular velocity.[9, 15] The quadriceps and hamstring muscles strength ratio has been postulated to be one of the many variables that contribute to knee joint stability and control.[10, 13, 15, 17, 20, 21, 26, 28, 31, 36, 40, 45, 46, 53-55] Presently, rehabilitation protocols emphasize the development of concentric strength in the agonist muscle groups but little attention is focused on the eccentric strength of the antagonist muscle group in the same motion.[46, 48, 79] Though the focus of these strength ratios have been shown to have some correlation to sport, there is no study that has proven these ratios to have any clinical relevance.[66, 80-85]

Objective measurements using the BIODEX® and or other similar isokinetic devices have produced numerous studies which have focused on the maximal isokinetic concentric quadriceps moment versus the maximal isokinetic concentric hamstring moment at a given angular velocity.[3, 9, 34, 44, 54, 55, 83] These studies have attempted to address the use of isokinetic dynamometry in the assessment of human muscle function. Various terms have been used for this H:Q ratio: reciprocal muscle group ratio,[54, 55] agonist:antagonist muscle ratio,[53] and torque ratio.[40] One review reported that the ratio could arguably be more important than the maximal moment for the assessment of human muscle function,[54] whereas another review concluded the H:Q strength ratio to be a distinctive parameter as a tool for return to sport when used as a measure for successful rehabilitation in individual subjects.[55] The review which stated that the ratio is more important than the maximal moment was referring to the need to consider the agonist/antagonist muscle relationship instead of just the peak strength of the agonist alone.[54]

Presently, there is no conclusive study which affirms either of these two views. The reasoning for the H:Q ratio to be more important than the maximal moment is due to muscle function. During normal gait or running patterns, the peak muscle force at a given angle is not as relevant as the cocontraction of the agonist and antagonist muscles during the active range of motion. The problem with this view point is that there are no other variables that are considered in the assessment of human muscle function. The second review[55] concludes that the H:Q ratio is one of the many parameters which should be considered when assessing muscle function. This conclusion appears to be more realistic since it would be unlikely that one component of a rehabilitation program would be an adequate assessment tool for return to work or sport activities. Other factors which should also be considered would be maximal moment of the H:Q complex, eccentric and concentric strength, flexibility, muscle endurance, proprioception, and kinaesthesia are other significantly important areas to consider in the assessment of human muscle function.

One significant limitation for isokinetic testing is the inability of the device to assess two joint muscles acting at two different joints at the same time. The hamstring and quadriceps (rectus femoris) muscles are biarticular muscles which cross the knee and hips joints respectively. All studies dealing with isokinetic H:Q ratios have focused their interest at the knee joint and thus not taken into account the influence of the hamstring and quadriceps muscles at the hip joint.[3, 9, 10, 13-15, 17, 18, 20-26, 28, 29, 31, 33-36, 39-41, 44-46, 48, 52-54, 56, 57, 59, 61, 62, 65-79, 81, 82, 86-132] As a result, various authors have criticised isokinetic assessment due to a perceived lack of external validity.[55, 133, 134] Thus, there is some doubt over the use of isolated single joint isokinetic testing muscle function assessment.[55] Presently there are more multi-joint sport specific isokinetic devices that are becoming available.[60, 99, 131, 135] Unfortunately more research is required to determine their reliability. Since the one joint isokinetic device is presently the most commonly for H:Q ratios, this study will not concern itself with the effects of the hamstring and quadriceps muscles at the hip joint.

True knee joint movement only allows eccentric hamstring muscle contraction to be combined with concentric quadriceps muscle contraction during knee extension or vice versa during flexion.[15, 41, 79] Due to this muscle contraction relationship, a more appropriate agonist-antagonist strength relationship for knee extension and flexion should be described as the relationship between the eccentric hamstring to concentric quadriceps moments (extension) and concentric hamstring to eccentric quadriceps moments (flexion) and the reverse for knee flexion. Unfortunately this area of strength ratio research is lacking.

The need for the data with respect to this new agonist-antagonist strength ratio would be important for musculoskeletal rehabilitation and profiling. The new ratio would be the eccentric quadriceps versus the concentric hamstring (Q_e:H_c) and the concentric quadriceps versus the eccentric hamstring (Q_c:H_e). An investigation of this agonist-antagonist strength ratio could lead to an enhanced understanding of the concentric and eccentric actions of the hamstring and quadriceps muscles in functional movements. The need for norms in functional strength could lead to sports-specific parameters for particular athletes and thus could be used as a screening and rehabilitation tool for return to sport.

Objectives of the Study

The aim of this study was to analyse the movement velocity as well as knee joint angle on the calculation of four different H:Q (H_c:Q_c, H_e:Q_e, H_e:Q_c, H_c:Q_e) strength ratios. The assessment of the eccentric and concentric strengths of the hamstring and quadriceps muscles was performed in each contraction mode at 30^0 of knee extension at isokinetic velocities of 30 and 150^0/sec.

Research Hypotheses

It was hypothesized that at angular velocities of 30 and 150^0/sec:

I. There would be no significant difference in four H:Q concentric and eccentric strength ratios between right and left lower limbs of the subjects

II. There would be a significant difference in the four H:Q strength ratios obtained during concentric and eccentric muscle contraction in maximal isokinetic knee extension and flexion movements

In order to compare the two different speeds (30 degrees/second and 150 degrees/second), it was hypothesized that:

III. There would be a significant difference in the ratios obtained during concentric and eccentric muscle contraction in maximal isokinetic knee extension and flexion movements at the faster velocity as compared to the slower velocity.[3]

Definition of Terms

Isokinetic exercise: Dynamic concentric or eccentric muscular activity performed at a constant angular velocity controlled by an external dynamometer.[13, 15, 17, 40, 53-55]

Angular velocity: The rate of change with respect to time of angular displacement, given in units of radians per second or degrees per second.[13, 15, 17, 28, 40, 53-55]

Concentric contraction: This type of muscle contraction occurs when the tension generated within the muscle is sufficient to overcome a resistance to move a body segment towards another segment (or the origin of the muscle in question) and thus the muscle shortens in length.[13, 15, 17, 25, 40, 53-55]

Eccentric contraction: This type of muscle contraction occurs when there tension generated within the muscle but the the muscle lengthens and moves away from the origin of the muscle in question.[13-15, 17, 25, 36, 40, 41, 44, 53-55, 79]

Isometric contraction: When a muscle is contracted without any appreciable change in muscle length.[13, 15, 17, 40, 44, 53-55]

Maximal Strength: the ability of a muscle group to exert maximal force in a single voluntary effort.[111]

Torque: A measure of a force that rotates an object about an axis of rotation. Torque is equal to the length of the lever arm, measured from the axis of rotation to the point of application of the force (in this case, the center of rotation of the lever arm), and multiplied by the component of force that is perpendicular to the lever arm.[3, 13, 15, 17, 40, 44, 48, 53-55]

Peak torque: The highest torque value of each contraction.[3, 13, 15, 17, 40, 48, 53-55, 57]

Work: This is the force required to move an object through a distance. The amount of work done by a force is the product of the amount of force in the direction of the displacement times the distance the resistance is moved. Work can be determined by the formula:

$$\text{WORK} = T \times 2\pi \times d$$

where T is the torque in Newton*meters, d is the portion of the arc travelled and π (pi) is a mathematical constant 3.14.[3, 13, 15, 40, 53-55]

H_e:Q_c: A ratio expression of the maximal eccentric hamstring torque divided by the maximal concentric quadriceps torque.[9, 15]

Q_e:H_c: A ratio expression of the maximal eccentric quadriceps torque divided by the maximal concentric hamstring torque.[9, 15]

H_c:Q_c: A ratio expression of the maximal concentric hamstring torque divided by the maximal concentric quadriceps torque.[9, 15]

Q_e:H_e: A ratio expression of the maximal eccentric quadriceps torque divided by the maximal eccentric hamstring torque.[9, 15]

Repetition: This is a single maximal effort of a subject at a specific testing velocity (30 or 150^0/sec) and type of muscle contraction (concentric or eccentric) for the quadriceps or hamstring muscle groups.

Trial: This is the average of four single maximal repetitions of a specific testing velocity (30 or 150^0/sec) and type of muscle contraction (concentric or eccentric) for the quadriceps or hamstring muscle groups.

Session: A session is the complete testing process for one subject which will include the four trials at each specific testing velocity (30 or 150^0/sec) and type of contraction (concentric or eccentric).

Delimitations

The following delimitation was applied to this study:

Two speed settings, 30 and 150 degrees per second, on the BIODEX® isokinetic exercise unit were selected for this study.[3, 17] The reason for choosing these two speeds was due to the fact that 30 degrees/sec[9, 10, 13, 15, 18, 21, 24, 31, 40, 44-46, 53, 54, 57] is the most common speed utilised in most studies, and 150 degrees/sec is the fastest available speed that the BIODEX® can produce eccentrically.

Limitations

The following limitations were applied to this study:

I. The precision of the torque readings was limited to the recording accuracy of the BIODEX® isokinetic apparatus, the BIODEX® software, the computer and manual calibration process.

II. The standardisation of the subjects position during the testing process and gravity correction.[3, 17] The BIODEX® has been found to produce highly reproducible knee flexion concentric strength data at 30, 60 and 180^0/sec.[3, 136-139]

III. The ability of each subject to exert a maximum voluntary effort during each test session and the individual subject's perception of maximum effort was beyond the control of the investigator.

Inclusion Criteria

Subjects were forty male healthy men who meet the following inclusion criteria:

I. They were between eighteen and thirty years of age.[9, 20, 39, 56, 59, 71, 128]

The rational for the use of males only in this study was due to the various ambiguities that were present in the research.[9, 20, 34, 59, 71, 117, 128] These differences are explained in greater detail in the review of literature. Since there has been no investigation of the H:Q ratio in this manner, the researcher only focused on males and attempted to determine if there was a significant difference in the H:Q strength ratios.

Exclusion Criteria

Subjects will be excluded from this study if they suffered or had suffered from:

I. Any significant hip/thigh/pathology [52, 136]
II. Any systemic diseases[52, 136]
III. An inability to understand consent.

Ethical Risk Considerations

A isokinetic dynamometry in general has proven to be relatively risk free.[3] The chance of any lower extremity injury is minimal as long as the stated contraindications mentioned in the exclusion criteria are followed. There has only been one reported case of muscle injury caused by isokinetic testing.[86] This was a case study,[86] in which the subject had suffered a recurrent episode of a left hamstring injury and was subjected to an eccentric isokinetic strength test which consisted of fifteen repetitions of the hamstring muscle three days after the injury using a KinCom dynamometer. Since the inclusion and exclusion criteria invalidated this case study subject from the present study, there was minimal risk of muscle strain injury in the thigh musculature.

Another potential cause for concern stated by the literature is the implication of delayed onset muscle soreness (DOMS).[6, 8, 36, 42, 86, 97, 140-142] These studies utilised an eccentric isokinetic protocol which consisted of twenty to forty repetitions[6, 36, 42, 140, 141, 143] and/or a testing procedure in which the subject was active from fifteen to sixty minutes.[6, 41] In this study, the subjects produced a maximum of eight eccentric repetitions and eight concentric repetitions. As a result of this short testing protocol, the data collection procedure took only 5 minutes. Due to this short testing time period and the very low number of repetitions, the potential discomfort experienced from DOMS was kept to a minimum and no complications occurred.

The subjects underwent a ten minute warm up on a treadmill at four miles per hour (mph) in order to prevent the possibility of any muscle strains in the thigh musculature.[3, 33, 44] Since this is a low threshold brisk walk on a treadmill there would be minimal if any secondary affects to the data collection procedure on the BIODEX®.[144] Care was taken to ensure that proper fastening of the subject to the isokinetic apparatus in order to prevent any unnecessary secondary movements and thus decrease the chance of an injury.[3, 14, 24, 33, 44]

Subjects were also told they could withdraw from the study at any time without prejudice as assumed in the human ethics agreement.

Chapter Two

Review of Literature

Human muscular strength refers to the ability of a muscle group to exert maximal force in a single voluntary effort.[111] The three methods currently available for measuring strength have been termed isometric, isokinetic, and isotonic.[118] A measurement of isometric strength, although valuable to the clinician, supplies only partial information about muscle function. The capacity of muscle to produce force can be assessed through either a static or dynamic contraction. Isometric (static) assessment reveals the amount of tension a muscle can generate against a resistance permitting no observable joint movement.[83, 104, 116, 128, 145, 146] Isotonic (dynamic) strength, the application of force through all or part of a joint's range of motion, can be assessed via a concentric or eccentric mode of contraction.[83, 104, 116, 128, 145-147] The term isokinetic is defined as the dynamic muscular contraction when the velocity of movement is controlled and maintained constant by a special device.[61, 83, 104, 116, 128, 145, 146]

Isokinetic Assessment

The ability of isokinetic dynamometers to display muscle force information through a joint range has been viewed as a major advantage of this technique when compared to other forms of dynamic exercise in which measurement of muscle is difficult to obtain.[13, 49-52, 54, 55] Isokinetic dynamometers allow the operator to specify the desired angular velocity, torque at the rotating joint as a function of time, and angle of displacement by the computer.[13, 49-52, 54, 55] In spite of this advantage, one should consider a number of limitations for accurate interpretation of isokinetic data.

Although isokinetic dynamometers permit a constant angular velocity to be designated by the user, the exercise limb must accelerate to the preset speed before isokinetic torque can be recorded.[69, 148-150] Similarly, the limb must decelerate at the end of the exercising range and a segment of the arc must be allocated for this to occur. It has also been shown that the limb continues to accelerate well beyond the dynamometer speed before the subject makes adjustments to control angular velocity.[13, 40, 149, 151] Sapega and colleagues[149] measured lever arm displacement and time during an isokinetic testing session. They found the dynamic loading of the hip abductors produced forty two to two hundred percent 'overshoot' at speeds of 30^0/s and 180^0/s. Osternig[151] reported that subjects accelerated their limbs through an arc of movement that exceeded the preset dynamometer speed by up to 150% before constant velocity was attained.

As the speed of the dynamometer increases, peak torque occurs later in the range of motion.[68, 152] Thus, at fast speeds of motion, the limb can pass peak torque prior to muscle reaching full tension. Therefore, the peak torque recorded may not represent the muscle's fullest torque capacity. Since the position at which peak torque occurs may vary with speed of motion, it is important to analyze maximal values at specific joint angles across speeds in addition to peak values generated throughout a joint range. Comparisons of peak torque across speeds irrespective of joint position may yield erroneous conclusions regarding the state of muscle function.

During an isokinetic assessment, there are a number of variables which influence force and power. The amount of force or power generated in a musculotendinous unit is greatly influenced by interactions between the characteristics of the muscle action (concentric or eccentric), muscle morphology the position at which force is measured, and the speed of movement.[13-15, 17, 24, 40, 53, 68, 152] Concentric isokinetic force velocity data partially simulate the classic inverse relationship curve derived from artificially stimulated, prepared muscle specimens in that they generally show a drop in peak force with increasing speed.[43, 80, 153] Isokinetic maximum performance is different as a function of angular velocity and depends on the type of action tested. The isokinetic moment velocity curve deviates from the force velocity curve of isolated muscles in that peak velocity may not be reached as quickly, may flatten or even decline when compared to in vivo studies.[13, 154, 155] Neural inhibition in the intact muscle may play a role in slowing the isokinetic force curve at slow speeds.[17, 43, 44, 156] Because measurements of absolute maximal force or velocity in human studies are subject to constraints, direct comparisons of in vivo to in vitro force velocity curves are limited.[13, 17, 157, 158] Muscle tension developed under the eccentric condition tends to increase with speed of muscle lengthening and can significantly surpass tension generated in voluntary maximum isometric actions.[44, 97] Whether eccentric torque rises or remains stable across increasing speeds appears to be dependent upon prior training, gender, muscle group, and joint position.[13]

The results from studies on the transfer of isokinetic measures and training across speeds vary.[13, 18, 53] The data suggest that measures of strength at a given speed do not accurately reflect relative strength at faster or slower speeds.[13, 18, 53, 55] Despite the limitations of isokinetic dynamometers, these devices provide a reliable means of measuring force, power, and velocity in many types of human movement.

Moment-Velocity Relationship

Isokinetic dynamometers enable assessment and exercise throughout a range of velocities.[3, 6, 8-10, 13-15, 17, 18, 20-23, 25, 26, 28-35, 39, 40, 43-47, 49-62, 64, 66-71, 73, 74, 76-82, 86-95, 97-104, 107-118, 120-130, 132, 137-139, 141-143, 148-151, 153, 154, 157, 159-173] Depending on instrumentation, this potential velocity may range from one to five hundred degrees per second. Accurate interpretation of an isokinetic evaluation requires an understanding of the force velocity relationship during both concentric and eccentric contractions.[15, 17, 24, 41, 49-52, 157, 158] The ability of muscle to generate concentric force is greatest at slow isokinetic velocities and decreases linearly as the test velocity increases.[41] The force velocity curve produced during eccentric exercise is quite different from the curve resulting from concentric muscular contraction.[41] The eccentric force remains the same or increases in force production as the test velocity increases.

The physiological mechanism for the discrepancy in the concentric and eccentric force velocity relationship appears to be related to differences in the binding and interaction of actin and myosin within the muscle sarcomere and the passive components of muscle tissue.[97, 140, 142, 143, 156, 174] Upon activation of the excitation contraction coupling mechanism, myosin binds to actin as inhibitory factors on the actin binding site are removed by the release of calcium.[45, 97, 143, 174] Once attachment has occurred, the potential energy stored in the myosin filament is transformed into the mechanical events of the cross bridge action.[8, 97, 140, 142, 143, 156] This produces tension, or concentric shortening of the muscle. If the external resistance exceeds the cross bridge ability to shorten (eccentric contraction), the actin myosin bond is broken before transduction of energy can occur.[17] As the external force continues, the energized myosin is repeatedly reattached and pulled apart from the actin without transduction of energy.

This eccentric process is further enhanced by the elastic elements of muscle tissue. It has been suggested that fewer motor units are activated under eccentric compared with concentric conditions.[110, 155] The elastic elements of the muscle provide the additional force exerted during eccentric actions.[130] The contributions of the elastic components to muscle force explains the greater concentric force exerted when eccentric action is performed before a concentric effort[130] and can be attributed to the storage and utilisation of elastic energy when the muscle lengthens.[46] Not only does this produce a greater tension at a given sarcomere length than does concentric contraction, it is also independent of velocity until the velocity of lengthening exceeds the binding rate of the actin and myosin. The practical application is that as velocity of concentric contraction increases, fewer cross bridges are formed and thus less force is produced. During an eccentric contraction, no energy is required for the cross bridge detachment and the crossbridges are exerting greater forces.[17] This mechanism could explain the greater tension produced at a given velocity under eccentric conditions.[9, 21, 27, 37, 44, 46, 52] For this reason, it has been postulated that the peak torque eccentric strength is higher than the peak torque concentric strength of the same muscle and/or the antagonist muscle.[9, 41, 79] But the research in this area has been lacking.

Isokinetic Exercise

A concentric contraction occurs when the tension generated within the muscle is sufficient to overcome a resistance (in most cases, at least gravity) to move a body segment (or the attachment of the muscle on that body segment) towards another segment (or the origin of the muscle in question) or vice versa. This type of contraction is dependant on one end of the muscle having more stability than the opposite end. The term dynamic shortening seems to be a more appropriate way of describing concentric contractions.

There are numerous studies that focus on knee flexion and extension isokinetic concentric strength. Many references have reported a decrease of concentric moment with increasing angular velocity.[73, 126, 144, 175] There is a relative amount of agreement with respect to isokinetic concentric reproducibility and application to the knee joint.[53, 94, 98, 108, 116, 145, 167] There have been differences found between gender[9, 20, 59, 71] and different age groups.[39, 56, 59]

On the other hand, there are conflicting results about the moment velocity relationship during eccentric isokinetic conditions. A large number of studies have found that, not only is eccentric moment greater than the corresponding concentric moment at each speed, but also the tension development during eccentric activations remains similar or increases slightly from slow to fast velocities.[52, 74, 89, 90, 109, 161] Westing et al.[89] reported that eccentric peak moment and angle specific moments of knee extensors and flexors, measured every 10^0 from 30^0 to 70^0 of knee flexion, did not significantly change between angular velocities of 0^0/sec and 270^0/sec. Griffin et al.[75] investigated the eccentric and concentric performance of knee elbow flexors and extensors. The eccentric/concentric ratio increased from slow to faster speeds.

A different moment velocity relationship has been reported by Walmsley et al.,[172] who examined this relationship during eccentric activations of the wrist extensors. They concluded that eccentric moments decreased as angular velocity increased. Mayer, et al.[107] tested the shoulder muscles of nineteen males and females over a range of velocities. It was found that both concentric and eccentric moments of the shoulder decreased with increasing angular velocity.

Some studies have found that the eccentric movement-velocity relationship is influenced by gender,[9, 20, 71, 128] age,[39, 56] and level of muscle strength.[117] Colliander and Tesch[128] reported that the female eccentric moment of both knee muscle groups increased with increasing speed, but in males, an increase only for the hamstrings moment output was found. Another study[34] found that males generated greater quadriceps isokinetic concentric relative and absolute torque values when compared to females in the same age category. Akima et al.,[59] concluded that peak torque during knee extension and flexion was inversely related to age in both men and women. This was irrespective of the speed of contraction in both genders. Two studies concluded that the difference between genders may also be the result of neural factors, such as muscle recruitment and or specific tension.[59, 117]

Quadriceps/Hamstring Strength Ratio

Strength training specialists have long recognized the importance of training both of the muscle groups producing opposite actions about a joint (flexors and extensors). It has been postulated that excessive imbalances in reciprocal muscle group ratios predispose the joint or weaker muscle group to injury. Because of this, the ratios about most major joints have received considerable attention in preseason screening and rehabilitation. Presently, it has been determined that the muscle group strength ratios are affected by age, sex, and level of activity.[9, 20, 39, 56, 59, 66, 67, 71, 81, 95, 104, 127, 129, 173]

The determination of an 'ideal' reciprocal muscle group ratio is confounded by several factors according to the literature such as, test velocity, gravity correction factor, age, gender, and testing protocol.[9, 20, 39, 56, 59, 66, 67, 71, 81, 95, 104, 127, 129, 173] It is interesting that virtually all studies of the lower extremity reciprocal muscle group ratios report concentric quadriceps to concentric hamstring or eccentric quadriceps to eccentric hamstring ratios. Nevertheless as the hamstring muscle group's eccentric contraction is essential for deceleration of knee extension during sprinting; this biomechanical observation would seem to support reporting of quadriceps concentric to hamstring eccentric muscle group ratios.

Although a wide range of ratios (0.43-0.90) have been reported for the ratio between concentric strength of the knee flexor and extensor muscles, one value (0.60) has gained wider acceptance than others.[176] Nosse[176] reported that while the clinical use of the 0.60 ratio has been widespread, the actual attainment of this value occurred under specific circumstances, that is, isometrically, with flexors and extensors measured at knee flexion angles of 15^0 and 65^0, respectively. Kannus[114] concluded that this ratio is a patient specific parameter, and general recommendations on its optimal value are difficult. Similar studies have discovered that as the isokinetic speed increases the concentric H/Q ratio increases whereas eccentric H/Q ratio was found either to remain similar to increase with increasing angular velocity.[13, 74, 77, 89]

Another important parameter is the H_e:Q_c ratio of tested muscles.[13, 15, 45, 74, 78] It was found that the concentric maximum moments of the hip, knee and ankle muscles were generally 90% of the corresponding eccentric maximum moments.[78] There are conflicts in the literature for the knee flexors which in one study reported to exhibit lower[72] or greater[128] H_e:Q_c ratios relative to knee extensors. But all of these studies agree that the H_e:Q_c ratio increases with increasing angular velocity.[15, 46, 73, 74, 128] Recent studies have proposed that combining data on conventional H:Q ratios with data on functional H:Q ratios and values of absolute strength would result in a more thorough description of the muscular strength properties at the knee joint than that revealed by the conventional H:Q ratio alone.[45, 46, 132]

Since the nature of many athletic and normal movements involves both concentric and eccentric actions, the H_e:Q_c and H_c:Q_e peak moment values may be more valid muscular parameters. Presently, there is conflicting research in this area in terms of knee flexor eccentric moment versus knee extensor concentric moment and vice versa. It was hoped that this study would shed some light on this area.

Chapter Three

Materials and Methods

Subjects

The subjects for this investigation consisted of forty males who were not engaged in a formal athletic program and between the ages of eighteen and thirty years of age (mean weight 81.5 kg, mean age 23).[9, 20, 39, 56, 59, 71, 128] A sample size calculation was performed in order to attain the minimum number of subjects required to achieve a statistical power of 0.80 (Appendix A). A formal athletic program encompasses any organised sport at the national, university, provincial, and or community levels. All subjects were right leg dominant (preferred to kick with the right leg) and all were requested to maintain their normal exercise and recreational activities. Subjects were recruited from the Department of Physical Therapy and Faculty of Physical Education and Recreation at the University of Alberta. A ten minute inclass presentation in several undergraduate classes was done to recruit subjects for the study after permission was obtained from the respective professors (Appendix B). Each subject read a participant information letter and gave his informed consent to perform the protocol described below, which was approved by the University of Alberta Ethics Committee (Appendix C).

Procedure

Instrumentation - Dynamometer

All testing was completed on the BIODEX® System II Isokinetic dynamometer (Biodex, Medical Inc., Shirely, NY). Permission to use the dynamometer was obtained (Appendix D) and testing occurred at the Edmonton Sport Institute (11828-111 Avenue, Edmonton AB, T5G 0E1). Previous investigators have established reliability coefficients for peak torque and angular velocity on several isokinetic dynamomters including the BIODEX®.[3, 138, 164] These studies have reported intraclass correlation coefficients (ICC) ranging from 0.67 to 0.98 for isokinetic peak torque and single repetition work at angular velocities of 60, 180, 240 and 300^0/sec.[138, 164] Due to this variable range in ICC values, an ICC test was performed on 10 trials prior to data collection and a value of 0.73 was determined for the concentric hamstring and quadriceps muscles at 30^0/sec at 30^0 of knee extension (Appendix F). A similar reliability test was done on 12 trials at 30^0/sec for the eccentric hamstring and eccentric quadriceps a value 0.96 (Appendix G). Subsequently, the BIODEX® was used for the assessment of concentric and eccentric quadriceps and hamstring strength. Data for these variables was recorded and analyzed with the BIODEX® Advantage Software v. 4.0 program (Biodex, Medical Inc., Shirely, NY).

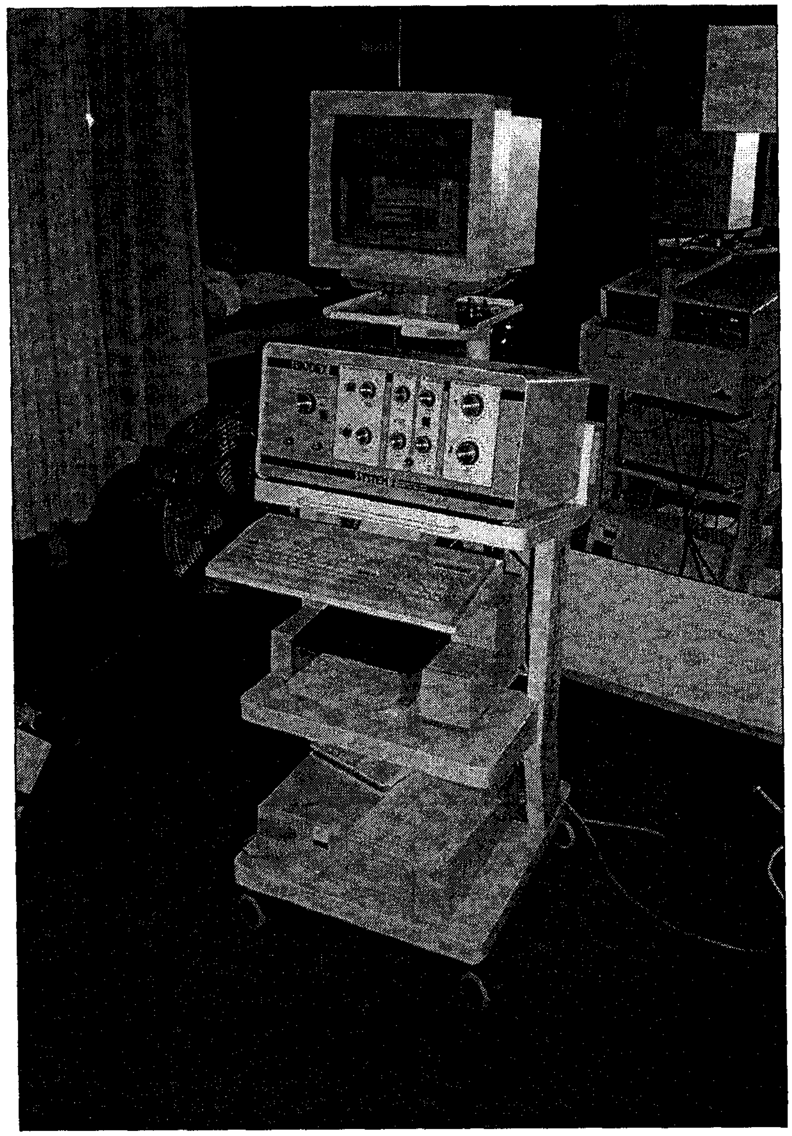

Figure 3.1 BIODEX® computer processor and software application

Isokinetic Strength Assessment

Prior to the isokinetic assessement each subject performed a standardised, 10 minute, pre-test warm-up. This warm-up consisted of a brisk walk on a Life Fitness TR-9100 treadmill at 4.0 mph and terminated at the ten minute mark. Each subject was then seated in the upright position and reclined to 10^0 on the isokinetic dynamometer chair. The subject was stabilized at the ankle, thigh, and pelvis using straps at each stated body part in order to minimise extraneous body movements (Figure 3.2).

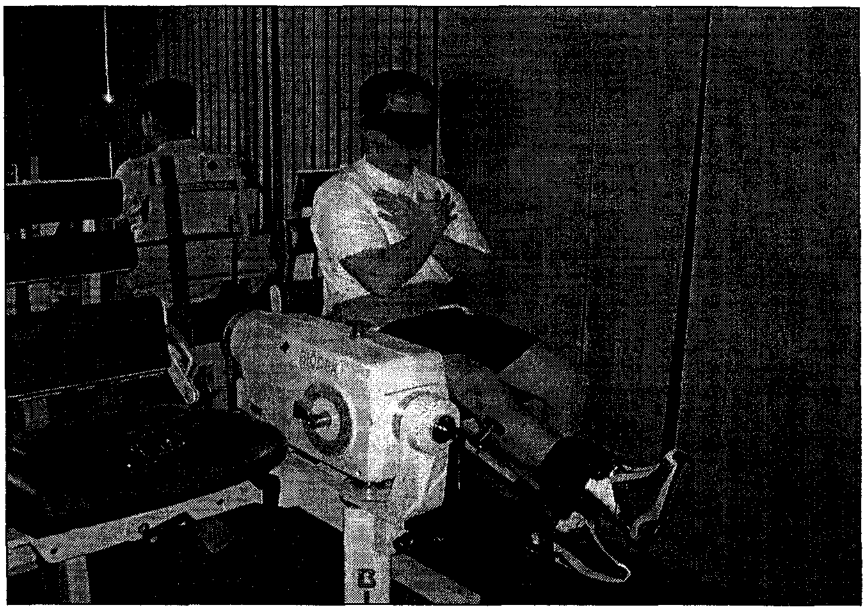

Figure 3.2 Subject strapped to BIODEX® apparatus and dynamometer

The lateral femoral epicondyle was used as the bony landmark for matching the axis of rotation of the knee joint with the axis of rotation of the dynamometer resistance adapter.[3, 6, 15, 39, 44, 56] The subject was placed in a position that allowed for a comfortable and unrestricted motion for knee extension and flexion from a position of 90^0 of flexion to 10^0 of terminal extension and hip flexion of 90^0. Because of safety precautions, the 10^0 to 0^0 range of motion was avoided in order to prevent the potentially hazardous combination of high muscular forces and tibial rotation, associated with the knee joint at full extension.[15] All peak torques were taken at 30^0 from full knee extension. These measures were taken in an attempt to identify and reproduce similar testing procedures for each individual subject. During the testing procedure, the subjects were required to cross their arms across their torso in order to prevent any secondary effects of hand grip on the isokinetic data.[177]

Gravity correction was obtained by measuring the torque exerted on the dynamometer resistance adapter with the knee in a relaxed state at terminal extension. Values for the isokinetic variables measured were automatically adjusted for gravity by the BIODEX® Advantage Software v. 4.0.[136] The BIODEX® manual recommends a software calibration on a monthly basis for both clinical and research use. To ensure software calibration, a 30 trial test was performed on the dynamometer for the concentric quadriceps and hamstring muscle groups. The peak torque for the quadriceps and hamstring muscle groups were recorded as well as peak torque for both groups at 30^0 at the knee joint. It was concluded that there was no deviation of the recording software apparatus when using a sample population of 10 trials using a t test for dependent means, $\alpha = 0.001$, $\gamma = 9$, two tail test. Thus a software dynamometer calibrated after every thirty trials showed stability. In addition, a hardware calibration was performed prior to the start of the data collection process.

Each subject was provided with a familiarization trial which consisted of five submaximal eccentric and five submaximal concentric efforts at 30^0/sec for knee flexion and extension producing a total of ten repetitions. All movements were performed with maximal effort for both concentric and eccentric knee extension and flexion. The BIODEX® software was set to automatically dampen the initial movements of the limbs to reduce the effects of torque overshoot as explained previously. Only four repetitions at each speed and contraction mode were performed and then averaged to produce the highest peak moment. The rest intervals between each trial was five minutes.[6, 15, 178] Angle specific torque at 30^0 of full knee extension was identified at 30^0/sec and 150^0/sec for both the right and left legs. Data was recorded for both maximal concentric and eccentric contractions of the quadriceps and hamstring muscle groups separately.

Each subject drew a predetermined randomised procedure before the start of BIODEX® data collection procedure that included both the randomisation of the right and left leg and the sequence of different muscle contraction types and speeds of contraction. This was done in order to reduce the possible learning effect and order effect that could occur if the procedure was done in sequential order of muscle group contraction and speeds.[50] During the testing procedure, there was no visual or verbal feedback given to the subjects. This was done to standardise the feedback given to the subjects during the testing procedure. At the initial start of the data collection procedure, the subjects were instructed to "push" or "pull" as hard as they possibly could throughout the available knee range of motion. Each contraction type and speed was performed separately with four repetitions given at each speed and type of contraction. This means there was a total of 16 repetitions or four trials for each leg with a five minute rest given at the end of every trial.

Isokinetic H/Q Strength Ratio

The purpose of this study was to examine the H_e:Q_c and H_c:Q_e peak moment values obtained in maximal isokinetic knee extension and flexion movements. This analysis included the influence of movement velocity as well as knee joint position and the agonist/antagonist $H_c:Q_c$, $H_e:Q_e$, $H_e:Q_c$ and $H_c:Q_e$ strength ratios for both knee flexion and extension. This was based on peak moments at angular velocities of 30^0/sec and 150^0/sec at 30^0 of terminal knee extension.[15, 45, 56] For example, $H_c:Q_c$ based on peak moments at 30^0/sec at 30^0 of knee extension was calculated by dividing peak concentric hamstring moment at 30^0/sec by peak concentric quadriceps at 30^0/sec.[15, 45]

Statistical Analysis

A t test for dependent means, α = 0.001, γ = 9, two tail test was done to test the recording apparatus using a sample population of 10 trials to test for reliability of the BIODEX® isokinetic apparatus. An ICC test was performed to determined the reliability for the concentric hamstring and quadriceps muscles at 30^0/sec. A similar reliability test was done at 30^0/sec for the eccentric hamstring and eccentric quadriceps. An analysis of variance (ANOVA) was used to compare the left and right legs with the two different isokinetic velocity settings and the two different contraction types. Thus a three-way [2 (right and left leg) x 2 (30^0/sec and 150^0/sec) x 4 ($H_c:Q_c$, $H_e:Q_e$, $H_e:Q_c$ and $H_c:Q_e$)] factorial design ANOVA with repeated measures was used to test for statistically significant differences (SPSS v. 11). This statistical test addressed the statistical differences between the right and left legs, the differences between the 2 different contraction speeds, and test for statistically significant differences between the H:Q strength ratios as stated in the research hypotheses. An alpha level less than 0.05 was be used to establish statistical significance.[6, 14, 15, 17, 21, 25, 28, 30, 31, 33-36, 43, 45, 47, 48, 56, 57, 168, 177]

Chapter Four

Results

There were no statistical significant differences noted between (Figures 4.1 and 4.2):

I. The strength ratios between the left and right legs within each tested isokinetic velocity (30^0/sec, 150^0/sec).

There were significant statistical differences found between (Figure 4.3):

I. The two isokinetic velocities of 30^0/sec and 150^0/sec with respect to the four H/Q strength ratios at 30^0 of knee extension ($p < 0.05$).

II. The four H:Q (H_c:Q_c, H_e:Q_e, H_e:Q_c, H_c:Q_e) strength ratios versus velocity of isokinetic contraction ($p < 0.05$).

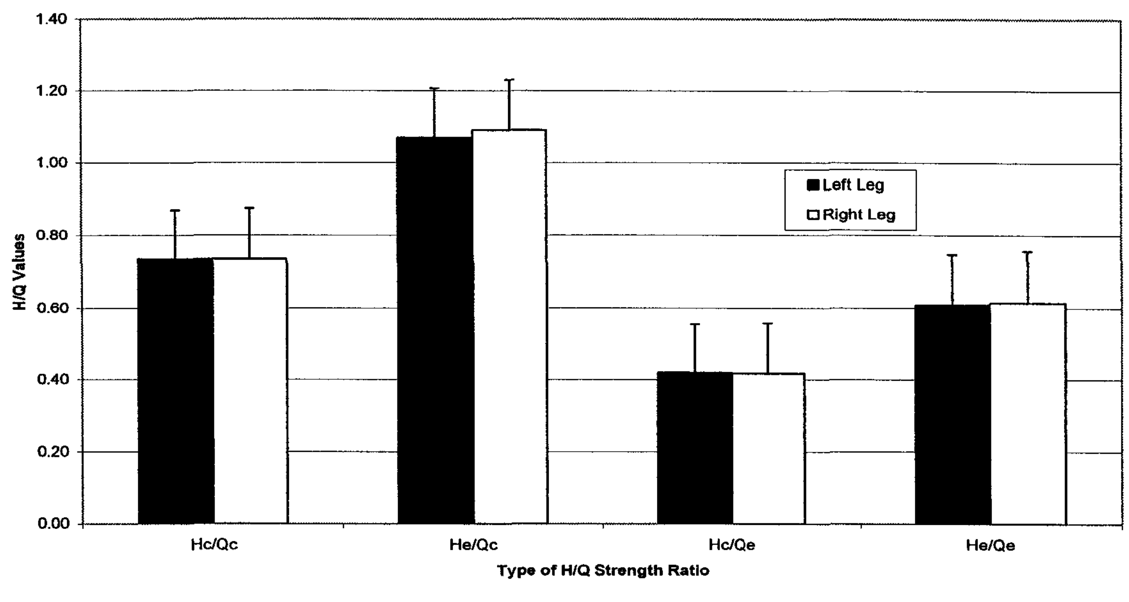

Figure 4.1 Left and right H/Q strength ratio at 30 degrees/sec (all comparison p > 0.05)

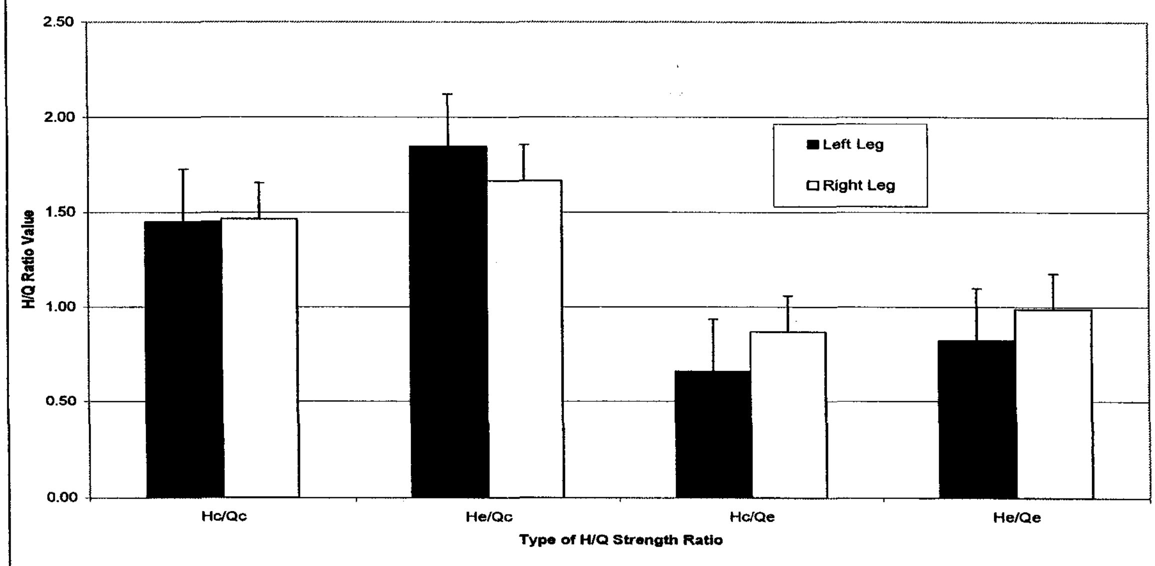

Figure 4.2 Left and right H/Q strength ratio at 150 degrees/sec (all comparisons p > 0.05)

The H:Q values of the left and right legs were very similar in all tested conditions.

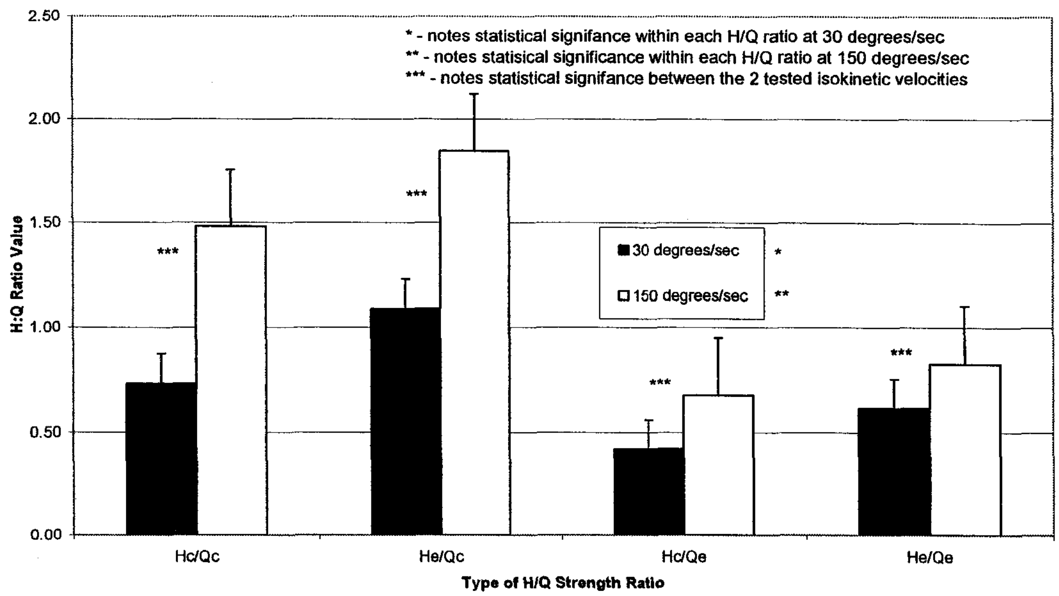

Figure 4.3 A comparision of the right H:Q strength ratios at 30 and 150 degrees/sec (statistical significant differences were noted between each speed and each ratio) ($p < 0.05$)

As the velocity of the two tested muscle contractions increased, so did the corresponding peak muscle torque contraction at 30^0 of knee extension for both the quadriceps and hamstring muscle groups. There were also differences noted within each H/Q ratio. Only the right leg was illustrated since there were no statistical differences noted between the two legs.

Table 4.1 Demographic data for subjects

	Mean	Range
Age	23 yrs	20 – 30 yrs
Weight	81.5 kg	69.5 – 100 kg

Table 4.2 H:Q strength ratios for both right and left legs at 30 and 150^0/sec

(n=40)

Velocity of Contraction	Leg	Type of H:Q ratio	Mean ratio	Standard Error
30 degrees/sec *	Right **	Hc:Qc *	0.73	0.008
		He:Qc *	1.09	0.035
		Hc:Qe *	0.42	0.007
		He:Qe *	0.62	0.017
	Left **	Hc:Qc *	0.73	0.014
		He:Qc *	1.07	0.040
		Hc:Qe *	0.42	0.007
		He:Qe *	0.61	0.020
150 degree/sec *	Right ***	Hc:Qc *	1.48	0.025
		He:Qc *	1.85	0.058
		Hc:Qe *	0.68	0.026
		He:Qe *	0.83	0.026
	Left ***	Hc:Qc *	1.45	0.024
		He:Qc *	1.84	0.047
		Hc:Qe *	0.66	0.026
		He:Qe *	0.82	0.025

* indicates statistical significance between the four H/Q strength ratios at each tested angular isokinetic velocity. ($p = 0.05$)

** indicates no statistical difference between right and left leg at 30^0/sec with respect to the four H_c:Q_c, H_e:Q_e, H_e:Q_c, H_c:Q_e ratios.

*** indicates no statistical difference between right and left leg at 150^0/sec with respect to the four H_c:Q_c, H_e:Q_e, H_e:Q_c, H_c:Q_e ratios.

Above is a summary of all four H:Q strength ratios at both 30 and 150^0/sec for both the right and left legs in table form.

Table 4.3 Mean right leg peak torque values for all tested subjects at 30 and 150^0/sec (n =40)

Velocity of Contraction	Muscle group	Type of contraction	Mean Peak Torque	SD +/-	Range
30^0/sec	Quadriceps	Concentric	77.3	12.1	55.2-101.1
		Eccentric	135.0	8.7	119.6-158.2
	Hamstring	Concentric	56.3	7.0	43.4-71.0
		Eccentric	83.6	18.5	51.1-123.1
150^0/sec	Quadriceps	Concentric	59.5	14.5	27.9-94.1
		Eccentric	129.3	12.6	104.0-164.9
	Hamstring	Concentric	86.9	18.3	50.0-126.2
		Eccentric	106.0	18.1	64.7-135.5

Table 4.3 provides descriptive data with respect to the peak torque values obtained for the right leg at each tested isokinetic velocity and each muscle contraction.

Chapter Five

Discussion

This study examined four (H_c:Q_c, H_e:Q_e, H_e:Q_c, H_c:Q_e) strength ratios at 30^0 of knee extension in the hopes of gaining a better understanding of the muscle forces acting at the knee joint. A better understanding of these forces could lead to a functional H:Q ratio as suggested in the literature.[15, 46, 121, 179]

Similar to a previous investigation[15], the results of this study indicated that the H_e:Q_c ratio at a faster velocity was significantly greater than the conventional H_c:Q_c ratio. As the isokinetic velocity increased, the hamstring muscle group had a greater contribution than the corresponding concentric quadriceps muscle group to the H_e:Q_c strength ratio as the knee approached full extension. The ratios included an eccentric versus a concentric component that were all above a 1:1 ratio. This greater ratio indicates a significant contribution for the antagonist muscles as it may counteract the concentric agonist muscle group at the end of knee extension. Also similar to previous studies[15, 20, 22, 28, 45, 50, 51, 59, 82, 88, 109, 165, 178, 180-183], there were no significant differences between the right and left legs at either of the two tested isokinetic velocities.

H:Q Ratios

As expected no significant differences were noted between the left and right legs at either isokinetic velocities of 30 and150^0/sec between the four H:Q strength ratios. This finding is consistent with earlier studies which have investigated H:Q strength differences between the right and left legs[70, 184] and with the first hypothesis of this study. Since the volunteers did not have any lower limb pathology or systemic diseases, the expectation was that there should not have been any statistical significant differences in strength between the two legs. Active daily movements such as walking or running, for example, are symmetrical activities so the stimulus to each leg would be similar. This finding is consistent with other studies which found that limb dominance does not produce significant greater isokinetic strength when compared to the non dominant leg isokinetic.[184, 185]

There was a significant discrepancy noted between the four H:Q strength ratios at both isokinetic velocities. This difference was expected due to the possible altered fibre type recruitment required during each tested velocity. At a higher velocity, following the principles of muscle recruitment, fast glycolytic fibres should be recruited in order to perform the tested knee action.[144, 175, 186] The increased speed of muscle recruitment required to produce the motion may engage a greater amount of slow and fast twitch muscle fibres which would produce a different strength pattern in the quadriceps or hamstring muscle groups to perform the tested knee extension or flexion action at the higher tested velocity.[186] As a result, all H:Q strength ratios increased with a comparable increase in the tested isokinetic velocity. This finding supports the second hypothesis of this study.

The differences between the four ratios can be clarified by understanding the components which produce an eccentric contraction. A rapid knee extension based on the force length and force velocity relationship suggests that high eccentric hamstring muscle forces and low concentric quadriceps muscle forces are generated. The key to the shape of the force length curve is the changes to the length of the myofibril at the sarcomere level.[8, 29, 168, 187] At resting length (about 2.5 μm), there are a maximum number of cross bridges between the filaments, and therefore maximum tension is possible.[175] As the muscle lengthens, the filaments are pulled apart, the number of cross bridges reduces, and tension decreases. At full length, (about 4.0 μm), there are no cross bridges and the tension reduces to zero.[175] As the muscle shortens to less than resting length, there is an overlapping of the cross bridges and interference takes place. This interference results in a reduction of tension that continues until a full overlap occurs, at about 1.5 μm.[175] The tension does not drop to zero but is drastically reduced by these interfering elements.

Force velocity characteristics for concentric contractions are such that as shortening velocity increases, there is a corresponding decrease in muscle tension.[8, 29, 168, 187] This loss in tension is due to the release and reforming of different cross bridges of the contractile element in a shortened condition. Also the viscosity found in the contractile element and the connective tissue increase causing an amplification of friction which requires an internal force to overcome, and hence results in a reduced tendon force.[175] Eccentric contractions have limited research in the area of force velocity characteristics. It is generally been postulated that for a given force, there is an increase in the velocity of shortening.[13, 20, 22, 25, 28, 31, 39, 41, 47, 97, 168, 174, 175, 178, 182, 186-190] This is due to general agreement in the literature that the force required to break the cross bridge protein link is greater than that required to hold it at isometric length, and this force increases as the rate of breaking increases. Second, the viscous friction of shortening is still a factor because the direction of shortening has reversed; and the tendon force must now be higher in order to overcome this internal damping friction. And the third aspect is the degree of contribution of the passive components of connective tissue which until recently have not been considered as a factor in eccentric contractions.[8, 24, 29, 33, 47, 97, 120, 140, 142, 143, 175, 187, 191-200]

The force velocity and force length relationship of the H_e:Q_e and the H_c:Q_c ratios would differ since the concentric ratio should be relatively lower to the eccentric ratio.[9, 21, 27, 37, 52] This phenomenon was not reproduced in the present study. The H_c:Q_c strength ratio at each leg for each respective velocity was greater than their H_e:Q_e strength ratio. The most plausible explanation would be the hamstring muscle group produced a greater concentric moment compared to its antagonist concentric quadriceps moment at terminal knee extension. This greater contraction would be due to the fact that at terminal knee extension, the hamstring is at its optimal length and able to produce a higher force contraction, while the quadriceps is shortening and thereby unable to generate an effective muscle force. For this reason, the numerator of the H:Q ratio would be larger than the denominator producing a larger H_c:Q_c value.

As the velocity of contraction increases the eccentric strength should also increase.[9, 21, 27, 37, 52, 74, 89, 109, 154, 161] The literature has clearly stated that the peak eccentric strength of the same tested muscle is generally greater than its peak concentric strength.[74, 89, 109, 154, 161] Thus, it would be reasonable to assume that the H_e:Q_e ratio should be higher than H_c:Q_c. There are a few reasons which may explain why this different ratio did not occur. As the velocity of contraction increased, the H_e:Q_e approached 1.0 (Table 4.2). This points toward a higher contribution of the hamstring muscle in relation to the quadriceps muscle as the velocity of movement increased. It is possible that the hamstring muscle group functionally operates in an eccentric manner and the quadriceps commonly functions in a concentric manner during daily activities. This assumption would be appropriate for the swing phase found in gait or running.[181, 201-203] Also, as the knee progressed closer to full extension, the hamstring muscles approaches their optimal length, and the quadriceps muscles are only capable of generating a declining force. If this assumption is correct, then the denominator of the H_e:Q_e would not be as large as the H_e value and this would be another reason explaining the difference between the H_e:Q_e and the H_c:Q_c strength ratio.

As the hamstring muscles approach their optimal length and the quadriceps muscles are only capable of generating a declining force, the high H_e:Q_c and H_c:Q_e ratios at knee extension are a result of these muscle force relationships. It is possible that at higher speeds and closer to terminal extension, the eccentric hamstring muscle force would be greater.[15] This is an area which requires further investigation in order to gain a better understanding of the contribution of the hamstring muscles in high velocity movement as the knee reaches extension. Since the eccentric strength of the hamstring or quadriceps muscles tend to increase at higher velocities and the corresponding concentric strength decreases, this would then explain why there was a statistically significant difference within the four tested H:Q strength ratios.

It is important to note that the terminal knee extension $H_e:Q_c$ strength ratio provides information which is more appropriate to the muscle pattern that is apparent at the knee joint.[15] In this study, the analysis of these two muscle groups was performed independently, and the issue of co-contraction can only be theorised. Even though the implication of the results of this study is limited, it does demonstrate the potential value of the $H_e:Q_c$ strength ratio with respect to terminal knee extension when compared to the other three tested H:Q strength ratios. The $H_c:Q_e$ ratio could provide information on terminal knee flexion as there is an eccentric moment of the quadriceps and a concentric moment which occurs at the same time in the hamstring muscle group. Since this motion was not examined in this study, information about the use of this ratio is limited. The differences between all four ratios at each of the two velocities support the third and final hypothesis of this investigation.

Coactivation of Antagonist Muscles

A general moment-velocity pattern was observed for the quadriceps and hamstring muscles: a relative decrease in concentric moment but constancy in eccentric moment with increase in speed. Consequently, $H_e:Q_c$ increased with increasing velocity of extension, indicating a potentially high muscular stability the knee joint during fast and forceful extension.[15, 46] Due to the moment-velocity pattern, an increased stabilizing effect might be expected at higher speeds and more extended knee angles than examined in the present study. A similar study suggested that the rise in H_e:Q_c ratios at the more extended positions was due to impaired length tension conditions for the quadriceps muscle (shortened) and at the same time, enhanced length-tension conditions for the hamstring muscles (elongated).[15] The significance of the present data remains to be determined with respect to normal function in vivo. However, data already exists which shows that co-contraction of the hamstring muscles is present during isokinetic extension, and this creates a substantial antagonist flexor moment at extended knee angles.[10, 13, 15, 17, 20, 21, 26, 28, 31, 36, 40, 45-47, 53-55, 121, 188]

Antagonist hamstring coactivation and its role in providing dynamic knee joint stability have been thoroughly investigated in the literature.[10, 13, 15, 17, 20, 21, 26, 28, 31, 36, 40, 45-47, 53-55, 79, 121, 147, 188, 204] Smith,[94] suggests that many types of joint movements require the coactivation of antagonist muscles. At the knee joint, co-activation of the hamstring muscles has been shown to reduce the anteriorly directed shear of the tibia relative to the femur that may occur during active knee extension.[10, 13, 15, 17, 20, 21, 26, 28, 31, 36, 40, 45-47, 53-55, 79, 121, 147, 204] The mechanical joint properties, such as joint stiffness, change with active joint moment.[205] However, this relationship may not be straightforward as the presence of agonist and antagonist muscles, which generate separately and independently of each other.[206] While, net joint moment is the difference between the moments exerted by the agonist and antagonist muscles; the joint stiffness is the sum of the individual stiffness of the agonist and antagonist muscles. Consequently, situations of both high net moment and low joint stiffness or low net moment and high joint stiffness may occur.[206] Antagonist coactivation of the hamstrings has been suggested to reduce the amount of anterior-posterior joint shear.[28, 46, 47, 79, 121, 147, 202, 204] In support of this notion, the tensile ACL stress created by contraction of the quadriceps muscle at extended knee joint positions is reduced by simultaneous coactivation of the hamstring muscles.[10, 13, 15, 17, 20, 21, 26, 28, 31, 36, 40, 45, 46, 53-55, 202, 204, 207, 208] Furthermore, the presence of antagonist coactivation is effective in dampening externally induced joint oscillation, even in situations where a myotatic reflex could create mechanical instability.[205] Evidence seems to support that the cerebellum plays an important role in switching from reciprocal activation to coactivation.[46, 147, 206, 209] Moreover, in certain types of joint movement, a common drive mechanism seems to exist by which the central nervous system may control the separate agonist-antagonist motoneuron pools as if they were one pool performing the same task. This drive or so called proportional motoneuron activation, appears to be present during either of two states: when uncertainty exists in the required task, or during anticipation of compensatory muscle forces.[206] It is not unlikely that the maximal dynamic knee extensions performed in the present study represented situations where compensatory hamstring muscle forces could be anticipated to regulate the contraction-induced ACL stresses described above. Hence, it seems reasonable that maximal isokinetic knee extension movements would involve patterns of proportional agonist-antagonist motoneuron activation.[147, 209]

This motoneuron activation has been suggested to lead to the braking observed by the hamstring muscles observed in fast knee extension.[15, 46, 54] A similar study discovered that this braking action was found to progressively increase as the knee joint reaches terminal knee extension.[15] They discovered that the H_e:Q_c ratios increased as they reached fast knee extension further supporting the breaking action of the hamstring muscles. This same study also established that H_c:Q_e values decreased for fast knee flexion. They concluded that the hamstring muscles may have a reduced capacity for dynamic knee joint stabilization in active knee movements that involve eccentric quadriceps muscle contraction. Table 4.2 displays the lower H_c:Q_e values which correspond to other similar studies.[45, 132] These two ratios appear to provide more information regarding the breaking action and the previously stated force length and the force velocity curves at the knee joint when compared to the H_c:Q_c ratios.

Eccentric exercise leads to structural signs of muscle damage. Most of the evidence shows sarcomeres out of alignment with one another, Z line streaming, regions of overextended sarcomeres or half-sarcomeres, regional disorganisation of the myofilaments, t-tubule damage and cytoskeletal protein damage.[8, 29, 33, 47, 97, 120, 140, 142, 143, 175, 187, 192-200] The precise details of the sarcomeres disruption process following eccentric contractions have yet to be determined. The differences between the maximal concentric strength and eccentric strength have been alluded to changes in muscle fascicle length. In previous studies[24, 210, 211], dynamic torque during knee extension has often been measured at a knee joint angle of 30^0, where relative fibre length has been found to be the similar. But in another study, this was found to not be the case.[24] Consequently, the length of the contractile component differed significantly with angular velocity even at the same joint angle, which has been assumed to be affected by the length change of the elastic component due to the forced exerted on the muscle-tendon complex. Furthermore, earlier research has suggested that the velocity of muscle-tendon complex is constant if angular velocity is fixed.[210, 211] This notion has also been disproved by another study.[24] This aforementioned study showed that the relationship between the knee joint angle and fascicle length differed with angular velocity. Major factors that cause these differences are thought to include 1) moment arm, 2) pennation angle, 3) elastic components, and excitation level of the nervous system.[97, 140, 192]

Changes in the moment arm associated with changes in the knee joint angle are considered to influence changes in the muscle-tendon complex. [212-214] Because the moment arm of a joint differs with the knee joint angle, the contraction velocity of the muscle-tendon complex is not constant even when the joint angular velocity is unchanging. The knee joint angle at which the moment arm reached its maximum was found to be different from the angle at which fascicle velocity was at its maximum, given any angular velocity.[215, 216] These results indicate the presence of factors that affect changes in fascicle velocity in addition to changes in the moment arm.

The pennation angle is the angle of insertion of a muscle fibre on its own common tendon. The relation between fascicle length and length of muscle-tendon complex is affected by pennation angle, which changes with the knee joint angle and the activation level.[217] When the knee is extended, length of muscle-tendon complex and fascicle length are reported to be shortened, and pennation angle increases.[217] In a similar study[24], when the knee was extended with maximum effort, pennation angle increased from 15^0 to 25^0 with changes in knee joint angle. After further investigation, it was concluded that the effect of pennation angle on the relationship between length of muscle-tendon complex and fascicle length is considered to be at this time nearly negligible.

Third, effects of elastic components such as the tendon and aponeurosis will be considered. The difference in fascicle velocity shortening observed between the two angular velocities was noted to be smaller than the difference between the joint angular velocities themselves, presumably because a greater force was produced at 30^0/sec with the same range of motion, causing greater extension of the tendon and hence greater shortening of the fascicle.[24] If the tendinous tissue is assumed to be very firm and does not change in length, the range of motion would be the same at 30 and 150^0/sec, and the change in the muscle-tendon complex and fascicle length would be identical as well. In a previous study,[218] the velocity of shortening of muscle fibres was found to be slower than the velocity of shortening of the muscle-tendon complex at all muscle lengths, and the ratio of these two variables also varied with the length of the muscle-tendon complex. This ratio has been reported to be affected by changes in the length of the aponeurosis associated with changes in tension.[24, 219] Another study indicated that change in the ratio of tendon length to muscle fibre length was dependent on a force exerted by muscle tissue.[97, 140, 191] All of these studies recommended considerating the effect of elastic components in the evaluation of mechanical characteristics of muscle-tendon complex.[24, 97, 140, 191]

Lastly, it has been suggested that the excitation level of the muscle during maximum isokinetic exercise was the same even when angular velocity varied.[210, 211] However an earlier study,[220] demonstrated, in electromyogram recordings from the extensor muscle of the knee, that the excitation level of the joint was not fixed throughout the range of motion. The authors reported that the excitation level of the muscle was not the same as that at maximum voluntary contraction over the entire range of motion at 30^0/sec. There is insufficient information about the activity level of the quadriceps muscle over various speeds. The excitation level of the muscle may in fact be relatively constant although it does seem to be affected by acceleration in the proximal part of the range of motion, and by deceleration in the distal part of the range of motion.[24] All of these factors contribute to the forces generated by eccentric contractions and they all, to some degree, will affect the force length and force velocity curves in knee extension.[8, 31, 97, 120, 187, 221]

A rapid knee extension based on the force length and force velocity relationship suggests that high eccentric hamstring muscle forces and low concentric quadriceps muscle forces are generated. As the knee reaches closer to extension, the hamstring muscles come closer to their optimal length, and the quadriceps muscles are only capable of generating a declining force. The high H_e:Q_c and H_c:Q_e ratios at knee extension are a partial result of these muscle force relationships. The H_c:Q_c and the H_e:Q_e ratios did increase as the velocity of contraction increased; but this was constant among all H:Q strength ratios. This was the only statistically significant change that occurred. No other inference can be made from these two strength ratios with respect to force length and force velocity relationships.

Architecture of Human Skeletal Muscle

The structure or architecture of the hamstring and quadriceps muscles are also factors influencing force production. The two most important muscle architectural parameters are muscle PCSA (physiological cross sectional area), which is proportional to maximum muscle force and muscle fibre length (proportional to maximum muscle excursion).[175] Each muscle is somewhat unique in terms of its architecture, taken as functional groups (e.g., hamstrings, quadriceps, dorsiflexors, and plantarflexors), a number of generalizations can be made regarding lower extremity muscles. Quadriceps muscles are characterised by their relatively high pennation angles, large PCSAs, and short fibres.[178, 180, 181, 222-225] In terms of design, these muscles appear suited for the generation of large forces. The hamstrings, on the other hand, by virtue of their relatively long fibres and intermediate PCSAs, appear to be designed for large excursions.[178, 180, 201, 203, 222, 224, 226-229] Specifically, note that the sartorius, semitendinosus, and gracilis muscles have extremely long fibre lengths and low PCSAs, which permit large excursions at low forces.[174] A general conclusion is that the antigravity extensors are designed more toward force production, and the flexors are designed more for long excursions.

The relatively high pennation angles of the quadriceps have been studied with respect to their muscle fibres.[230] Researchers, using muscle biopsies, demonstrated much greater fibre type percentage variability between animal subjects than within subjects. Fibre type variability was 5-10% within a muscle but as much as 30% between the same muscles of different animal subjects. Another issue to consider is that muscle fibres of the thigh do not extend the entire length of the muscle and a natural gradation exists in fibre-type percentage and thus motor unit types from superficial to deep within a muscle.[175] Because motor units are activated in a stereotypical fashion from slow to fast,[175] duration and amplitude of motor unit recruitment may be affected and understanding of this muscle activation has not been clearly determined. Another issue of complexity is the demonstration of muscle compartmentalization[174, 231, 232] where distinctly different motor nerves innervate separate portions of muscles with unique fibre-type distributions. As a result, their activation pattern and general level of use can differ, in spite of the fact that they are in the same muscle.

Clinical Implications

There is conflict in the research with respect to the use of isokinetic testing and injury prevention but all of these studies have utilised the conventional H_c:Q_c

strength ratios across various velocities and joint angles.[10, 13, 15, 20, 21, 26, 28, 36, 40, 45, 46, 53-55] Chronic eccentric exercise is characterised by adaptations which result in several functional modifications to muscle.[14, 17, 41, 97, 140, 142, 143, 156, 165, 174] These modifications have lead to an increase in the hamstring muscle strength which has been theorised to counteract anterior directed forces at the knee joint and thus reduce stress on the anterior cruciate ligament (ACL).[10, 13, 17, 20, 21, 26, 28, 29, 31, 36, 40, 46, 47, 53-55, 121, 188, 204] There have also been studies which have shown a post injury ACL repair increase in maximal isokinetic quadriceps and hamstring muscle strength and a lower degree of variance between the right and left legs with respect to H:Q ratios that can lead to a successful return to functional activities.[10, 15, 31, 53, 57, 59, 68-70, 93, 102, 109, 114, 127, 128, 180, 181, 225, 228]

It is possible that in some sports, the microdamage from mild eccentric exercise may, progress to more significant tears as a result of the demands placed on the muscle by the event. If so, then a way to counteract the problem would be to subject athletes to a mild eccentric exercise program to cause an adaptation to muscles at risk against further damage. This adaptation by eccentric strength training has shown to increase both strength and fibre area of a muscle compared to concentric strength training.[8, 13, 25, 29, 33, 47, 97, 120, 142, 143, 174, 175, 178, 187, 188, 190, 193, 233, 234] The increased strength and fibre area may protect the muscle from possible muscle trauma. There is also an increase in the muscle stiffness resulting in a greater improvement in performance activities of such as jumping.[235] Because the tendon was thought to be the source of passive tension, the production of passive tension and storage and release of elastic recoil energy in skeletal muscle had been considered negligible.[236] However, coupling the physiology of lengthening muscles with the emergent knowledge of the cytoskeletal proteins within the muscle cell, it is becoming clear that these proteins contribute greatly to the storage of elastic energy. Specifically, the passive tension produced by a myofibril may be produced by an elastic titin filament, whereas collagens and intermediate filaments become important as a muscle reaches end range.[8, 29, 97, 120, 142, 143, 174, 175, 190, 193, 233, 234] This elastic property combined with the long muscle architecture of the hamstring muscles, may be of greater significance than presently thought regarding the role of eccentric contractions and in terminal knee extension.[8]

Since the eccentric component of the hamstring muscles can assist with ACL/knee stability,[10, 13, 15, 17, 20, 21, 26, 28, 31, 36, 40, 46, 47, 53-55, 121] the H_e:Q_C or the H_C:Q_e strength ratios would be more reliable markers for dynamic knee joint movements. A rehabilitation program that monitored the H_e:Q_C could indicate whether more high-resistance strength training should be performed for the knee flexors or extensors, ideally including an eccentric strength training program. This H_e:Q_C strength ratio in particular is important since, as the lower limb reaches full knee extension, there is a concentric moment of the quadriceps and an eccentric moment which occurs at the same time in the hamstring muscle group. Concentric strength programs have been shown to increase the eccentric strength of the same contracting muscle and therefore both types of contractions are beneficial for the stimulated muscle.[9, 13, 17, 23, 50, 52, 61, 115, 120, 121, 175, 178, 182, 187, 237] But it is the eccentric component of a program that leads to the increase in titin and other cytoskeletal components which result in a more movement specific pattern as one reaches terminal knee extension in a high speed movement.[8, 29, 97, 142, 143, 187, 193, 194, 197-199, 233, 234, 238-241] The need for functional movement patterns that include the use of an eccentric movement of the antagonist muscle and the associated neural patterns have been shown to be more rehabilitation specific for an individual.[17, 31, 209, 242-244] These neural patterns, as discussed previously, are specific to the type movement, muscle contraction and motor neuron pool which vary throughout the entire range of motion.

Chapter Six

Conclusion

In conclusion, there is muscle adaptation that occurs with eccentric exercise which may be a potential means of protecting athletes against muscle injuries.[8, 24, 29, 33, 97, 120, 142, 175, 187] This adaptation leads to increases in strength and size as well as alterations in the passive properties of the muscle.[8, 24, 29, 33, 97, 120, 142, 175, 187, 191-200] It also appears that eccentric contractions require unique activation strategies by the nervous system.[187, 220] These predictable responses have clinical and physical performance consequences. Stability of the knee joint gradually changes as terminal extension is reached. The force velocity and force length relationships of skeletal muscle are enhanced by the use of the H_e:Q_c and H_c:Q_e strength ratios when compared to the H_c:Q_c and H_e:Q_e strength ratios. At terminal knee extension, the eccentric strength of the antagonist muscles is higher than the concentric agonist muscles and this relationship increases as joint velocity is increased. Together, the hamstring and quadriceps muscles act to stabilise the knee in dynamic movement. At the knee joint, coactivation of the hamstring muscles has been shown to reduce the anteriorly directed shear of the tibia relative to the femur that may occur during active knee extension.[10, 13, 15, 17, 20, 21, 26, 28, 31, 36, 40, 45-47, 53-55, 79, 121, 147, 204] and it is hypothesised that this is relationship can be better monitored through the H_e:Q_c and H_c:Q_e strength ratios. The data from this study seem to support this notion.

As a result, a combination of the both the conventional H_c:Q_c and H_e:Q_c or H_c:Q_e strength ratios would provide a better understanding of the strength relationship in the knee joint for assessment purposes. The assessment of the knee joint using these parameters can indicate a possible agonist/antagonist muscle imbalance which may lead to knee joint instability and muscle trauma.

Further research in different ranges of motion, velocities, types of subjects (types of athletes), and relation to functional outcome measures are required to gain a better understanding of the knee joint. Also an investigation into the utility of the H_e:Q_c and H_c:Q_e strength ratios as a possible screening outcome measure for return to sport or injury prevention is another area to consider. The need for an investigation of functional movement and the muscle strength relationships in those types of motions are other topics for future research. Presently, there is ambiguity in the literature about the ability of males and females to generate eccentric moments of the knee flexors and extensors eccentrically.[34, 59, 117, 128] There is also conflicting results on the issue of age[39, 56], level of activity[117], and gender[9, 20, 71, 128] with rehabilitation and isokinetic strength testing. Another area of research opportunity is the determination of the 'ideal' reciprocal muscle group ratio testing protocol. This protocol would lead to the development of what that ratio value or normative value should be, and which type of muscle contraction should be utilised to formulate the strength ratio. This study has attempted to explain the use of the H_e:Q_c strength ratio and its relevance to strength testing and possibly for rehabilitation purposes.

Despite the conflict in the research regarding the knee flexor eccentric moment versus the extensor concentric moment,[9, 20, 34, 59, 71, 74, 89, 109, 117, 128, 172] more research is needed to explore this H_e:Q_c strength ratio. In this study, it is apparent that the eccentric strength of the antagonist muscle was greater than the concentric agonist muscle and this relationship was dependent on the speed of contraction but was not different between the right and left legs of the same subject. Of the four H:Q ratios analysed, the H_e:Q_c strength ratio displayed more relevant information at terminal knee extension with respect to the eccentric and concentric strengths of the quadriceps and hamstring muscles as well as the force velocity and force length relationships. These results suggest that a focus on the eccentric component of the antagonist muscle group is just as if not more important than the concentric agonist muscle group as one reaches the late stage of the rehabilitation program. This switch in focus of muscle group may lead to an increase in joint stability and thus a prevention of future injury.

There appears to be a reciprocal muscle strength relationship between the eccentric antagonist muscle and the agonist muscle in knee extension and flexion. This significant relationship, is best demonstrated by the hamstring muscle, which produced a statistically significant H_e:Q_c strength ratio when compared to the present H_c:Q_c strength ratio at the knee approached extension. Since a difference has been found, the H_e:Q_c strength ratio should be utilised for knee joint movement analysis. This would suggest towards the need for a standard or a normative data set and whether or not the strength ratios are variable in the population. Another area of prospective investigation would be to determine if there is a variation in the H_e:Q_c strength ratio in different sports or positions of the same sport due to the dissimilar demands placed on the athletes.

A final area of potential research would be the development of an isokinetic apparatus which can test functional movements and hence determine a true strength ratio relationship without the present limitations that the BIODEX® and other similar isokinetic devices present. Even though this is presently underway in the literature[131, 135, 245], it is very early in development and necessitates more research.

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Appendix A

Sample Size Calculation

This study was a [2 (right and left leg) x 2 (30^0/sec and 150^0/sec) x 4 (H_{con}/Q_{con}, H_{ecc}/Q_{ecc}, H_{ecc}/Q_{con} and H_{con}/Q_{ecc})] factorial design with repeated measures. There is only one other study similar to this thesis[15] the observed statistical difference in strength ratios was obtained with a sample size of n=9. Therefore, conservatively, it was assumed that the effect size was classified as medium. According to Cohen, a medium effect using ANOVA at $\alpha = 0.05$ is F= 0.25 (Cohen, 1977, pg 286). The sample size needed to get a statistical power of 0.8 was n=39, u=4 (Cohen, 1977, table 8.3.15, p 317). [246]

Thus, a sample size of forty will allow for one subject to leave the study for any reason and preserve the power of the study.

Appendix B

Letters Permission for the Undergraduate in Class Presentation

UNIVERSITY OF ALBERTA

To Whom it may concern
Health Ethics Research Board
University of Alberta
Capital Health Region

Re: Permission of Matthew Pulickal to recruit students from my class for his masters thesis

This letter is to confirm that I have given Matthew Pulickal permission to speak to the male students of my physical therapy class at the end of one of my classes so that he can recruit them for his study. I will ensure that there is no pressure put on the students to participate & the students will be informed that their participation in Matt's study will in no way influence their marks in the course.

If you have any questions, please do not hesitate to contact me

Yours truly,

David J. Magee
Professor

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August 14, 2003.

TO WHOM IT MAY CONCERN

RE: Permission to Recruit Research Subjects

Please accept this letter as written permission for Matt Pulickal to attend and address my PEDS 200 (Physiology of Exercise) undergraduate class early in the fall term of 2003, with the purpose of recruiting subjects for his master's thesis project. I am aware of the purpose and methodologies of the study and support it without reservation.

Yours truly,

Dr. D.G. Syrotuik, Professor
Faculty of Physical Education and Recreation

Appendix C

Participant Information Letter and Consent Form

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Participant Information Letter
Title: Evaluation of Eccentric and Concentric Hamstring and Quadriceps Strength Ratios

This study is part of a research requirement for a Masters of Science in Physical Therapy. Although many studies are now available concerning muscle performance in athletes, this research has largely been confined to studies of muscular strength ratios in the front and back thigh muscle groups. The many studies examining muscle strength ratios have normally only reported the contraction of muscle strength ratios for the bending of the knee and the straightening the knee.

The purpose of this study is to analyse the muscle strength ratio of both the muscles which bend and straighten the knee joint More specifically, the type of muscle contraction and lengthening strength of the muscles that bend and straighten the knee will be analysed separately and left and right limbs will be compared with regards to highest muscle strength ratios

The study will involve one practice session (10-20 min) followed by one testing session (20-40 min) performed on the same day and will be arranged at your convenience. Thus the study will take about one hour of your time. If you agree to participate in the study, you will be asked not to perform any strenuous physical activity for at least 48 hours prior to each testing session.

When you arrive in the laboratory, your height and weight will be measured and then you will be asked to perform a warm-up which consists of a brisk walk on a treadmill until you start to perspire. You will then be asked to sit in the BIODEX® chair and you will have a strap placed around your ankle to connect you to the testing machine. You will be firmly secured in the chair by means of straps around your thigh and across the pelvis and chest.

As a warm-up and familiarization procedure, you will perform five to ten submaximal contractions of the muscles which bend and straighten the knee joint at the preset speed for that session, followed by three to five identical maximal repetitions. A two minute rest period will be given before the actual test starts.

The strength test itself consists of a four 45 second trials of high speed bending and straightening of the knee with the speed selector set at 30 degrees per second for one session and at 150 degrees for the other session. Both legs will be tested each time. The muscles on the front and back of the thigh will be analysed in a shortening and lengthening contraction mode separately. You will be asked to ensure that you are making a maximal effort with each contraction throughout the test and to work as fast and as hard as you can. You will not be verbally encouraged by the investigator.

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The major risk associated with participation is that related to muscular soreness following the contraction efforts. This discomfort is expected to be minor and similar to that which you may have experienced previously after exercise to which you were unaccustomed. A secondary risk relates to the possible development of knee discomfort as a result of the high intensity contraction efforts. Such discomfort is uncommon and usually temporary when it occurs. If you develop knee joint pain at any time during the study your participation in the study will be immediately stopped. If there is any muscle soreness present after the testing process ice will be applied to the sore muscles for 15 minutes in order to reduce any further muscle soreness. If there is muscle soreness later, you should apply ice 4 times a day for 15 minutes of application time and to continue your normal activity level in a pain free range of motion. If these symptoms persist call Mathew Joseph Pulickal at 439-5351. I (the researcher) will then verbally instruct you to see a medical doctor if necessary or give you the necessary physical therapy advice as needed to alleviate these symptoms. The results of this study will be offered as examples of possible normal values for the muscles on the front and back part of the thigh in terms of peak muscle strength in the thigh. With expanded profile data about the muscle performance characteristics of various categories of athletes, training and rehabilitation programs may be adapted to meet the strength, speed and endurance requirements of a given sport.

Any questions you may have before, during or after the sessions will be gladly answered.

You have the right to withdraw from participation at any time for any reason without bias.

All information and data collected during the study will be property of the investigators and kept confidential at all times. The data collected will be stored on a 3 ¼ floppy disk and will be treated as a medical chart. This means it will be kept in a secured room for five years in the clinic and access to the room is restricted. Access to the data will be restricted to those conducting the study and the subjects to their respective data, except where written approval is given by the subject to provide specific individuals with their data.

Please retain this explanation for your own records. Thank you.

In the event that questions concerning the study arise, please feel free to contact Mathew Joseph Pulickal, at 451-1234 (work) or 439-5351 (home), his graduate advisor Dr. David Magee at 492-5765 (office) or the Associate Dean of Graduate Studies and Research for the Faculty of Rehabilitation Medicine, Dr. Paul Hagler at 492-9674.

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CONSENT FORM

UNIVERSITY OF ALBERTA

Title: Evaluation of Eccentric and Concentric Hamstring and Quadriceps Strength Ratios

Investigators: Mathew Joseph Pulickal, M.Sc. Graduate Student, Phone: 439-5351
David Magee, Professor, Faculty of Rehabilitation Medicine, Phone: 492-5765

CONSENT:

I, ________________________________, agree to participate in the above named project conducted by Mathew Joseph Pulickal, Physical Therapist and Masters Student and Dr. David Magee, Professor, Department of Physical Therapy, University of Alberta.

	Please circle	
Do you understand that you have been asked to be in a research study?	Yes	No
Have you read and received a copy of the attached information sheet?	Yes	No
Do you understand the benefits and risks involved in taking part in this study?	Yes	No
You had an opportunity to ask questions and discuss the study?	Yes	No
Do you understand that you are free to refuse to participate or withdraw from the study at any time? You do not have to give a reason and it will not affect your care.	Yes	No
Has the issue of confidentiality been explained to you? Do you understand who will have access to your records/information?	Yes	No

With my signature below, I indicate that I understand all that is required of me in this study; I acknowledge receipt of a copy of the information and consent forms.

This study has been explained to me by the following investigator, ________________ Date: ____________

______________________ Participant's Signature   ______________________ Please Print Name

______________________ Witness's Signature   ______________________ Please Print Name

______________________ Date

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

Researcher: ________________   Printed Name: ________________

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Appendix D

Letter of Permission to Utilise the BIODEX® System II Isokinetic Dynamometer for Testing

SPORT INSTITUTE PHYSIOTHERAPY INC.

August 12, 2003

TO: University of Alberta Health Research Ethics Board Panel B

FROM: Debbie Steadward, BScPT
Director of Physiotherapy

I, Debbie Steadward, Director of Physiotherapy at Sport Institute Physiotherapy, give Mathew Joseph Pulickal, BScPT, permission to use the BIODEX machine at Sport Institute Physiotherapy. Therefore, he has authorization to recruit his subjects from the University of Alberta undergraduate Physical Therapy and Physical Education departments and test them according to his thesis testing protocol at Sport Institute Physiotherapy using the BIODEX isokinetic apparatus. The clinic is in full support of his study and is in agreement with the ethical considerations involved in subject testing at our facility.

Yours truly,

Deborah Steadward BSc P.T.

Debbie Steadward, BScPT

DS/ds

Sport Institute Physiotherapy Inc.

11828 - 111 Avenue
Edmonton, Alberta
T5G 0E1

Ph: (780) 451-1234
Fax: (780) 452-9303

Appendix E

Statistical Analysis for Software Calibration

t test for dependent means, α 0.001, γ = 9, two tail test				
Group	Trial 1	Trial 2	D	D^2
Quads 1	86.4	89.2	-2.8	7.84
Quads 2	87.9	87.8	0.1	0.01
Quads 3	86.7	86.7	0	0
Quads 4	87.6	85.9	1.7	2.89
Quads 5	87	82.6	4.4	19.36
Hams 1	90.7	89.5	1.2	1.44
Hams 2	88.6	92.6	-4	16
Hams 3	91.4	90.5	0.9	0.81
Hams 4	91.1	89.6	1.5	2.25
Hams 5	88.6	87.7	0.9	0.81
		Sum	3.9	51.41

t_{cal} dependant = 0.7445281

t_{crit} dependant = 4.781

$t_{cal} < t_{crit}$, df=9, alpha=0.001, 2 tail test

$\therefore$ There are no statistical significant differences between the 2 testing sessions.

Appendix F

Intercorrelation Coefficient Using a Repeated Measures ANOVA for Concentric Hamstring and Quadriceps Contractions at 30⁰/sec

ICC for concentric hamstring and quadriceps muscles at 30^0/sec					
Source of Variance	Sum of Squares	df	Mean Squares	F	P
Between Subjects	74.67	9			
Within Subjects	25.71	10			
Treatment	0.76	1	0.76	0.27	< 0.05
SXT	24.95	19	2.77		
ICC	0.73				

Appendix G

Intercorrelation Coefficient Using a Repeated Measures ANOVA for Eccentric Hamstring and Quadriceps Contraction at 30⁰/sec

ICC for eccentric hamstring and quadriceps muscles at 30^0/sec					
Source of Variance	Sum of Squares	df	Mean Squares	F	P
Between Subjects	3338.79	9			
Within Subjects	225.56	10			
Treatment	40.386	1	40.386	1.96	< 0.05
SXT	185.17	19	20.57		
ICC	0.96				